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REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY

OF MOLYBDENUM AND MOLYBDENUM-BASE ALLOYS

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DEFENSE METALS INFORMATION CENTER

BATTELLE MEMORIAL INSTITUTE

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REVIEW OF RECENT DEVELOPMENTS IN THE TECHNOLOGY OF MOLYBDENUM AND MOLYBDENUM-BASE ALLOYS

J. A. Houck*

Introduction

This memorandum is a brief review of recent developments in the metallurgy of molybdenum and molybdenum-base alloys. It covers information made available to the Defense Metals Information Center during the period from April 1, 1960, to June 30, 1961.

The Wah Chang Corporation(1)** reports that the leaching of calcium-reduced molybdenum in hydrochloric acid removes impurities and improves arc-melting characteristics. Arc-melted ingots have been produced using leached calcium-reduced, hydrogen-reduced, and electron-beam melted starting materials. These are to be converted to sheet and evaluated for property differences.

In their sheet-rolling program for the Bureau of Naval Weapons(2), Universal-Cyclops has completed the fabrication of seven Mo-0.5Ti sheet bars to 0.060-inch-thick sheet. Each sheet bar represented a variation in melting or primary fabrication practice. Single- and double-melted ingots 8 and 12 inches in diameter were used. Fabrication variables included direct extrusion to sheet bar as well as extrusion to intermediate rounds followed by forging or rolling to sheet bar. Average yields from conditioned ingot to finished sheet were as follows:

Extruded sheet bar	- 68 per cent
Forged sheet bar	- 49 per cent
Rolled sheet bar	- 45 per cent

Chemistry, recrystallization behavior, and room-temperature tensile and bend properties were among the parameters used to evaluate the sheet obtained. The results showed no advantage of double melting over single melting, and an 8-inch-diameter ingot was recommended for use in Phase II of this program. The use of extruded sheet bar for primary fabrication was also recommended.

In a study of molybdenum-alloy sheet produced by powder-metallurgy processes(3), Sylvania is exploring the properties of alloys containing small additions of titanium and/or zirconium and tungsten in amounts to about 30 per cent. Generally, hot strength in the alloys prepared by powder-metal techniques has not been up to the levels achieved in the same alloys made by arc casting. However, one powder-metallurgy alloy, Mo-0.5Ti-0.043C, was as strong as arc-cast Mo-0.5Ti at 2200 F.

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*Principal Metallurgist, Nonferrous Metallurgy Division, Battelle Memorial Institute.

**References are listed on page 3.

Arc-cast Mo-0.5Ti-0.08Zr(TZM) alloy has been forged at "true hot working temperatures" ranging from 3182 to 3542 F and subsequently cold worked to produce a strain-hardened structure.(4) Preliminary test data from this Westinghouse program indicate that improved yield and ultimate strengths can be attained by initially working this alloy at these temperatures.

Metallurgical Properties

Significant improvements in both high-temperature tensile strengths and creep-rupture strengths in the Mo-1Ti-0.1Zr-0.14C(TZC) alloy by precipitation hardening has been reported by Chang.(5) For example, the following data show the effect of heat treatment prior to swaging on the 2200 F/100-hour rupture strength:

Heat Treatment	2200 F/100-Hour Rupture Strength, psi
(a) 1 hour at 3000 F	32,000
(b) 5 hours at 3500 F	38,000
(c) 5 hours at 3750 F	50,000
(d) (c) + 2750 F/16 hours	48,000

The studies on molybdenum-base alloys have been completed with the determination of strength properties of heat-treated but nonworked Mo-TZC and Mo-TZ (Mo-1Ti-0.1Zr-0.005C). The results show that, at the appropriate temperatures, the tensile and rupture strengths can approach or even exceed those of the worked condition. This results primarily from a fine, strain-induced precipitate composed of carbides of molybdenum, titanium, and/or zirconium.

A program at Advanced Metals Research Corporation, aimed at identifying the dispersed phases in refractory-metal alloys, has indicated the two principal precipitates in the Mo-TZC alloy are Mo_2C and TiC.(6)

The Climax Molybdenum Company(7) reports hot-hardness data on experimental alloys of molybdenum and tungsten that were both arc melted and cast under vacuum. The highest elevated-temperature hardnesses were displayed by a complex alloy prepared from a base alloy nominally 50Mo-50W. A W-0.002Zr-0.002C alloy was softer than molybdenum-base alloys in the 500-2800 F temperature range.

The Chromalloy Corporation(8) reported that explosive forming appears superior to conventional forming methods for arc-melted Mo-0.5Ti alloy sheet. In the explosive-forming operation, formability improved as the strain rate increased. This is contrary to results obtained with unalloyed molybdenum and alloyed powder-metallurgy molybdenum.

REFERENCES

(1) Fairgrieve, D. S., Baroch, Edmund, and Wong, James, Wah Chang Corporation, Albany, Oregon, preliminary information under a Navy contract.

(2) Universal Cyclops Corporation, preliminary information under a Navy contract.

(3) Nelson, R. C., Bargainier, Roger B., and Tiala, Lauri D., Sylvania Electric Products, Inc., preliminary data under a Navy contract.

(4) Bonchak, J., Westinghouse Electric Corporation, preliminary information under an Air Force contract.

(5) Chang, W. H., General Electric Company, Cincinnati, Ohio, preliminary information under an Air Force contract.

(6) Cuff, F. B. Jr., Advanced Metals Research Corporation, preliminary information under an Air Force contract.

(7) Barr, Robert O., Chesmar, G. S., and Semchyshen, M., Climax Molybdenum Company, Detroit, Michigan, preliminary information under an Air Force contract.

(8) "Explosive Forming of Refractory Metals", Chromalloy Corporation, Final Technical Report, Contract NOas 59-6265-c (December 31, 1960).

LIST OF DMIC MEMORANDA ISSUED (CONTINUED)

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A list of DMIC Memoranda 1-61 may be obtained from DMIC, or see previously issued memoranda.

DMIC Memorandum Number	Title
62	Effects of Rate of Heating to Aging Temperature on Tensile Properties of Ti-2.5Al-16V Alloys, August 18, 1960, (PB 161212 $0.50)
63	Notes on Large-Size Electrical Furnaces for Heat Treating Metal Assemblies, August 25, 1960
64	Recent Developments in Superalloys, September 8, 1960, (PB 161214 $0.50)
65	Compatibility of Rocket Propellants with Materials of Construction, September 15, 1960, (PB 161215 $0.50)
66	Physical and Mechanical Properties of the Cobalt-Chromium-Tungsten Alloy WI-52, September 22, 1960, (PB 161216 $0.50)
67	Development of Refractory Metal Sheet in the United States, September 20, 1960, (PB 161217 $0.50)
68	Some Physical Properties of Martensitic Stainless Steels, September 28, 1960, (PB 161218 $0.50)
69	Welding of Columbium and Columbium Alloys, October 24, 1960, (PB 161219 $0.50)
70	High Velocity Metalworking Processes Based on the Sudden Release of Electrical Energy, October 27, 1960, (PB 161220 $0.50)
71	Explosive Metalworking, November 3, 1960, (PB 161221 $0.50)
72	Emissivity and Emittance--What are They?, November 10, 1960, (PB 161222 $0.50)
73	Current Nickel-Base High-Temperature Alloys, November 17, 1960, (PB 161223 $0.50)
74	Joining of Tungsten, November 24, 1960, (PB 161224 $0.50)
75	Review of Some Unconventional Methods of Machining, November 29, 1960
76	Production and Availability of Some High-Purity Metals, December 2, 1960
77	Rocket Nozzle Testing and Evaluation, December 7, 1960
78	Methods of Measuring Emittance, December 27, 1960
79	Preliminary Design Information on Recrystallized Mo-0.5Ti Alloy for Aircraft and Missiles, January 16, 1961
80	Physical and Mechanical Properties of Some High Strength Fine Wires, January 20, 1961
81	Design Properties as Affected by Cryogenic Temperatures (Ti-6Al-4V, AISI 4340, and 7079-T6 Alloys), January 24, 1961
82	Review of Developments in Iron-Aluminum-Base Alloys, January 30, 1961
83	Refractory Metals in Europe, February 1, 1961
84	The Evolution of Nickel-Base Precipitation-Hardening Superalloys, February 6, 1961
85	Pickling and Descaling of High-Strength, High-Temperature Metals and Alloys, February 8, 1961
86	Superalloy Forgings, February 10, 1961
87	A Statistical Summary of Mechanical-Property Data for Titanium Alloys, February 14, 1961
88	Zinc Coatings for Protection of Columbium from Oxidation at Elevated Temperatures, March 3, 1961

LIST OF DMIC MEMORANDA ISSUED
(Continued)

DMIC Memorandum Number	Title
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91	The Emittance of Titanium and Titanium Alloys, March 17, 1961
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93	A Review of Recent Developments in Titanium and Titanium Alloy Technology, March 27, 1961
94	Review of Recent Developments in the Evaluation of Special Metal Properties, March 28, 1961
95	Strengthening Mechanisms in Nickel-Base High-Temperature Alloys, April 4, 1961
96	Review of Recent Developments in the Technology of Molybdenum and Molybdenum-Base Alloys, April 7, 1961
97	Review of Recent Developments in the Technology of Columbium and Tantalum, April 10, 1961
98	Electropolishing and Chemical Polishing of High-Strength, High-Temperature Metals and Alloys, April 12, 1961
99	Review of Recent Developments in the Technology of High-Strength Stainless Steels, April 14, 1961
100	Review of Current Developments in the Metallurgy of High-Strength Steels, April 20, 1961
101	Statistical Analysis of Tensile Properties of Heat-Treated Mo-0.5Ti Sheet, April 24, 1961
102	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, April 26, 1961
103	The Emittance of Coated Materials Suitable for Elevated-Temperature Use, May 4, 1961
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108	Review of Recent Developments in the Technology of Tungsten, May 18, 1961
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110	Glass Fiber for Solid-Propellant Rocket-Motor Cases, June 6, 1961
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112	Review of Recent Developments in the Evaluation of Special Metal Properties, June 27, 1961
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